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MORPHOMETRIC ANALYSIS OF THE UPPER CRETACEOUS BRAZILIAN SIDE-NECKED TURTLE *BAURUEMYS ELEGANS* (SUÁREZ, 1969) (PLEURODIRA, PODOCNEMIDIDAE) [1]

(With 3 figures)

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ABSTRACT: The Upper Cretaceous Brazilian side-necked turtle *Bauruemys elegans* is a basal branch of Podocnemididae. Several well preserved topotypes of *B. elegans* were collected during field work in the last decade and a quantitative study of its morphologic variation is, therefore, feasible. Forty characters that represent distances of two landmarks (*e.g.* intersections between bone plates) were analyzed. The investigation was performed through multivariate exploration via Principal Component Analysis (PCA). Neural series measurements have shown little variation, whereas vertebral scute series were more variable. Only a single specimen was out of 95% ellipse of PC2 and PC3 of comprised measurements of the plastron and this out plot was interpreted as due to ontogenetic difference. No other specimen showed significant difference to the medial values, corroborating the null hypothesis that the sample represents a unique population of *B. elegans* and the observed variation would be explained by different age stages.

Key words: *Bauruemys elegans*. Principal Components Analysis. Pirapozinho site. Testudines.

RESUMO: Análise morfométrica da tartaruga do Cretáceo Superior brasileiro *Bauruemys elegans* (Suárez, 1969) (Pleurodira, Podocnemididae).

A tartaruga Pleurodira do Cretáceo Superior brasileiro *Bauruemys elegans* é um ramo basal de Podocnemididae. Diversos topótipos bem preservados de *B. elegans* foram coletados durante trabalhos de de campo realizados nas últimas décadas e um estudo sobre sua variação morfológica é, portanto, viável. Quarenta caracteres (medidas) representando distâncias entre dois marcos anatômicos (*e.g.* interseções entre placas ósseas) foram analisados. A investigação foi realizada através de exploração multivariada via Análise de Componentes Principais (PCA). As medidas da série neural apresentaram pequena variação em relação às da série vertebral, que se mostraram mais variáveis. Somente um único exemplar ficou fora da elipse de 95% para os PC2 e PC3 das medidas do plastrão e este desvio foi interpretado como devido a diferenças ontogenéticas. Nenhum outro espécime apresentou diferenças significativas dos valores médios, corroborando a hipótese nula de que a amostra é representativa de uma única população de *B. elegans* e de que a variação observada pode ser explicada como devida a diferenças etárias.

Palavras-chave: *Bauruemys elegans*. Análise de Componentes Principais. Sítio de Pirapozinho. Testudines.

INTRODUCTION

The site of Pirapozinho, informally called "Tartaruguito", was discovered during the construction of Sorocabana railroad in 1950's (Suárez, 1969a,b,c; 2002). Situated in the municipality of Pirapozinho (west of São Paulo State, 22°13'08"S; 51°25'59"W, Fig.1) this is the type-locality of *Bauruemys elegans* (Suárez, 1969), a basal branch of Podocnemididae (Kischlat, 1996; Romano & Azevedo, 2006), that corresponds to the single fossil turtle from Bauru Basin which is represented by cranial and post-cranial materials. Yet, four other nominal Testudines taxa have been proposed to Bauru Basin, namely: *Roxochelys harrisi* (Pacheco, 1913), *Bauruemys brasiliensis* (Staeche, 1937), *Roxochelys wanderleyi* Price, 1953, and *Cambaremys langertoni* França & Langer, 2005. In most recent revisions, *R. harrisi* was considered a *nomen dubium* and *B. brasiliensis* was only tentatively allocated in *Bauruemys* (Kischlat, 1994; Kischlat *et al.*, 1994),

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corresponding to an *incertae sedis* (Oliveira & Romano, 2007). Nevertheless, França & Langer (2005) assumed that *Cambaremys langertoni* might represent a juvenile form of *Bauruemys brasiliensis* and that this uncertainty could not be dismissed until more complete specimens are recovered.

Several well-preserved specimens attributed to *B. elegans* were collected at "Tartaruguito" site during field work performed in the last ten years and a quantitative approach is feasible. Classical morphometric studies have been carried out with living pleurodiran turtles in order to determine population structure and sex ratio, mainly in species of *Podocnemis* (*e.g.*: Kuchling, 1988; Valenzuela *et al.*, 1997; Escalona & Fa, 1998; Valenzuela, 2001; Fachín-Terán *et al.*, 2003; Fachín-Terán & Vogt, 2004). However, this kind of approach is rare in paleontological studies (*e.g.*: Forster, 1996; Christiansen, 1999).

Preliminary taphonomic studies (Henriques *et al.*, 2002, 2005) suggest that a single population of *B. elegans* is represented in the sample collected at "Tartaruguito". We analyzed some specimens collected at this locality to investigate if significant variation could be determined. The quantitative information was explored using bivariate and multivariate morphometric shape analysis, in order to test the null hypothesis suggested by taphonomic analyses.

MATERIAL AND METHODS

A total of 18 topotypes of *Bauruemys elegans* (MN 4327-V, MN 6674-V, MN 6761-V, MN 6762-V, MN 6771-V, MN 6772-V, MN 6782-V, MN 6789-V, MN 6790-V, MN 6791-V, MN 6795-V, MN6796-V, MN 6797-V, MN 6798-V, MN 6800-V, MN 6807-V, MN 7015-V, MN 7016-V) from the collection of the Departamento de Geologia e Paleontologia, Museu Nacional, Universidade Federal do Rio de Janeiro (DGP/MN/UFRJ) were examined in this study. All specimens were prepared with traditional techniques (May *et al.*, 1994).

We employed 24 carapace and 16 plastron characters which were separated into three sorts of quantitative data matrix (covariance matrix): (1) total lengths and width, (2) comprised measurements of the carapace, and (3) comprised measurements of the plastron. The turtle shell provides numerous landmarks for depicting morphological variation in a objective way, and it is easy to identify homology between the elements of the shell and determinate quantitative characters. All characters represent distances of two landmarks (*e.g.* intersections between bone plates; see Fig.2) and measurements of the neural plates were preferred since it is the most variable elements of the turtle shell (Pritchard, 1988). Measurements of all characters are in mm and were made by Pedro Romano using Mitutoyo micrometer (Stainess-Hordened) of 150 and 1000mm.

All statistic analyses were conducted using the software PAST version 1.15 (Hammer *et al.*, 2003). Descriptive statistics (including arithmetic means, standard deviation, median, maximum and minimums values) of all 40 characters were calculated in order to express the variation of each one. Multivariate analyses were performed using exploration via Principal Component Analysis (PCA). The PCA is one of the simplest of the multivariate methods and the objective of this analysis is to take some variables and find combinations of these to produce indices (the variance or eigenvalues of the PC) that are uncorrelated, which means that the indices are measuring different dimensions in the data (Manly, 1986). If the original variables are highly correlated, positively or negatively, mean that the variables are adequately represented by two or three principal components and that there is a good deal of redundancy in the data if there is very high correlation (Manly, 1986).

Since all characters analyzed represent linear measurements, we aim to investigate if the variation between the specimens is significant and/or if there is a pattern of distribution in the sample. Therefore, each specimen was scattered in order to seek for difference among specimens, and each character was loaded in order to show what degree the original variables are different of principal components. However, our analyses do not consider the possibility of polimorfism and sexual dimorphism as eventual explanations for the variability observed since those explanations need *a priori* assumptions undetectable on the sample (*i.e.*: discrete categories of characters, as tail length, which might be used to determine sexual dimorphism).

Abbreviations: (TLC) Total Length of Carapace; (TWC) Total Width of Carapace; (LN) Length of Nuchal; (LN1) Length of first Neural; (LN1) Length of first Neural; (LN2) Length of second Neural; (LN3) Length of third Neural; (LN4) Length of fourth Neural; (LN5)

Length of fifth Neural; (LN6) Length of sixth Neural; (WN) Width of Nuchal; (WN1) Width of first Neural; (WN2) Width of second Neural; (WN3) Width of third Neural; (WN4) Width of fourth Neural; (WN5) Width of fifth Neural; (WN6) Width of sixth Neural; (LS1) Length of first Scute; (LS2)- Length of second Scute; (LS3) Length of third Scute; (LS4) Length of fourth Scute; (WS1) Width of first Scute; (WS2) Width of second Scute; (WS3) Width of third Scute; (WS4) Width of fourth Scute; (TLP) Total Length of Plastron; (TWP) Total Width of Plastron; (LEP) Length between Epiplastra; (LEN) Length of Endoplastron; (LHY) Length of Hyoplastra; (LHP) Length of Hypoplastra; (LXI) Length of Xiphiplastra; (WEN) Width of Endoplastron; (WHH) Width between Hyo-Hypoplastron; (WHX) Width between Hypo-Xiphiplastron; (LGU) Length of Inter-gular Scute; (LHU) Length of Inter-humeral Scute; (LPE) Length of Inter-pectoral Scute; (LAB) Length of Inter-abdominal Scute; (LFE) Length of Inter-femoral Scute; (LAN) Length of Inter-anal Scute.

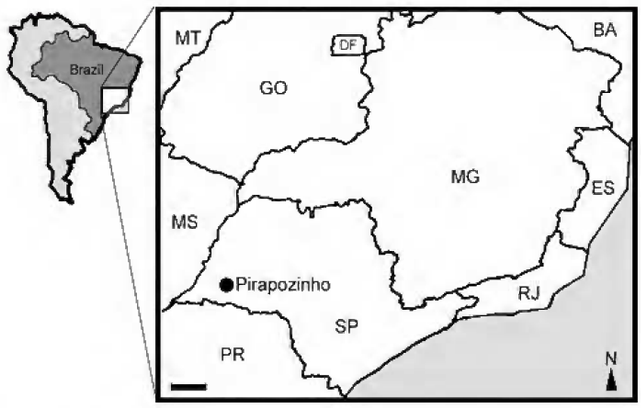

Fig.1- Map of southwester Brazil . Dot indicates location of Pirapozinho site from which the specimens were collected (22° 13' 08'' S; 51° 25' 59'' W). Scale bar: 100 Km. Acronyms: BA (Bahia State), DF (Distrito Federal), ES (Espirito Santo State), GO (Goiais State), MG (Minas Gerais State), MS (Mato Grosso do Sul State), MT (Mato Grosso State), PR (Paraná State), RJ (Rio de Janeiro State), SP (São Paulo State).

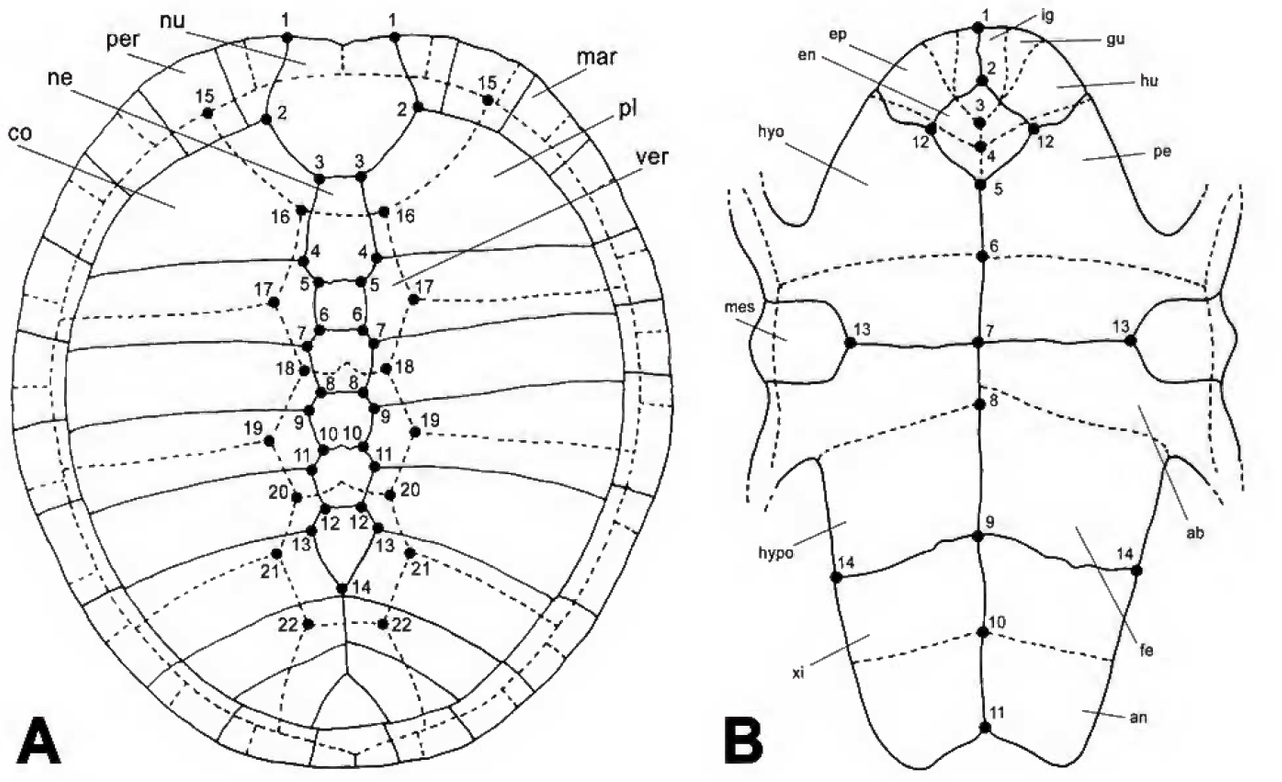

Fig.2- Landmarks of carapace (A) and plastron (B) used to trace linear measurements. The 14 quantitative characters (linear vectors) are indicated at tables 1 and 2. Figure based on specimens MN 6674-V; MN 6762-V and MN 6772-V. Abbreviations: (ab) abdominal scute, (an) anal scute, (co) costal bones, (en) endoplastron, (ep) epiplastron, (fe) femoral scute, (gu) gular, (hu) humeral scute, (hypo) hypoplastron, (hyo) hyoplastron, (ig) intergular, (mar) marginal scute, (mes) mesoplastron, (ne) neural plates, (nu) nuchal bone, (pe) pectoral scute, (per) peripheral bones, (pl) pleural scutes, (ver) vertebral scutes, (xi) xiphiplastron.

RESULTS

The descriptive statistics of all characters are sumarized in Table 1. As expected, the total length and width characters (TLP, TWP, TLC, TWC) have shown the biggest variation amplitude. Neural series measurements (LN, LN1, LN2, LN3, LN4, LN5, LN6, WN, WN1, WN2, WN3, WN4, WN5, WN6) have shown little variation whereas vertebral scute series (LS1, LS2, LS3, LS4, WS1, WS2, WS3, WS4) were more variable. Plastron characters (LEP, LEN, LHY, LHP, LXI, WEN, WHH, WHX, LGU, LHU, LPE, LAB, LFE, LAN) have shown equivalent variation.

PCA were performed to three classes of characters from three distinct covariance matrix (Fig.3). The first three principal components obtained from a covariance matrix of total lengths and width respond for 88.298% of the total variation (PC1 = 60.704%, PC2 = 26.057 e PC3 = 1.537%). The first three principal components obtained from a covariance matrix of comprised measurements of the carapace respond for 80,213% of the total variation (PC1 = 49,532%, PC2 = 21,497% e PC3 = 9,184%).

TABLE 1. Descriptive statistics of the three sorts of characters analyzed (total length and width, comprised measurements taken from the carapace, and comprised measurements taken from the plastron) including mean values (Mean), standard deviation (SD), median values (Median), number of entries (N), and smallest and largest values (Max and Min).

	Characters	Vector*	Mean	SD	Median	N	Max and Min
Total length and width	TLC	---	275.4	35.7	279.4	8	348.0 – 225.0
	TWC	---	230.8	42.2	220.0	7	317.5 – 185.0
	TLP	---	236.5	41.7	218.05	6	299.4 – 189.0
	TWP	---	182.2	33.9	165.5	7	242.5 – 149.0
Comprised measurements taken from the carapace	LN	1-2	37.4	10.6	33.0	8	60.2 – 26.0
	LN1	3-4	36.9	4.4	37.5	9	44.6 – 27.4
	LN2	5-6	19.6	3.2	19.2	10	27.6 – 15.0
	LN3	6-8	25.4	3.8	24.6	9	33.1 – 20.5
	LN4	8-10	22.6	3.5	22.0	10	30.7 – 18.3
	LN5	10-12	23.0	4.6	22.7	12	34.0 – 18.2
	LN6	12-14	25.1	7.6	23.8	11	45.5 – 16.1
	WN	2-2	47.9	8.3	45.6	6	64.6 – 38.7
	WN1	4-4	24.4	3.9	24.1	10	33.4 – 18.0
	WN2	5-5	16.9	1.8	17.0	10	21.4 – 14.0
	WN3	7-7	23.9	3.7	24.0	10	33.5 – 20.0
	WN4	9-9	23.8	3.8	23.6	10	33.6 – 19.0
	WN5	11-11	25.6	6.1	23.8	12	43.0 – 20.3
	WN6	13-13	24.1	6.3	23.0	11	40.6 – 16.4
	LS1	15-16	42.3	6.8	41.8	9	56.3 – 31.4
	LS2	16-18	55.6	7.2	56.1	11	68.5 – 43.0
	LS3	18-20	49.9	10.7	46.8	12	79.0 – 38.6
	LS4	20-22	46.9	10.7	44.1	11	76.0 – 35.3
	WS1	15-15	70.1	8.0	68.9	7	84.0 – 58.4
	WS2	17-17	62.5	6.5	61.8	9	76.2 – 54.0
	WS3	19-19	60.3	7.7	60.5	10	79.0 – 51.0
	WS4	21-21	56.6	12.8	51.7	11	89.4 – 45.0
Comprised measurements taken from the plastron	LEP	1-2	20.7	3.6	20.65	8	25.4 – 14.3
	LEN	2-5	43.8	10.1	39.6	9	60.1 – 33.5
	LHY	5-7	67.5	20.4	62.5	12	130.0 – 50.5
	LHP	7-9	45.7	9.4	41.6	13	62.5 – 35.6
	LXI	9-11	63.4	8.0	63.2	13	80.5 – 53.2
	WEN	12-12	44.2	9.9	40.15	10	60.4 – 32.2
	WHH	7-13	59.4	12.7	56.9	13	89.4 – 46.0
	WHX	9-14	48.2	6.7	48.1	13	61.3 – 40.5
	LGU	1-3	43.3	9.7	39.1	8	62.0 – 33.4
	LHU	3-4	10.1	3.3	9.4	11	19.6 – 7.1
	LPE	4-6	41.6	9.9	41.35	12	60.4 – 25.7
	LAB	6-8	50.6	10.0	46.8	13	70.1 – 38.4
	LFE	8-10	57.8	9.5	55.8	12	80.0 – 42.9
	LAN	10-11	33.8	4.7	33.2	13	44.3 – 27.7

Measurements of all characters are in mm; (*) landmarks used to trace linear measurements. See figure 2.

The first three principal components obtained from a covariance matrix of comprised measurements of the plastron respond for 92,507% of the total variation (PC1 = 48,403%, PC2 = 23,944 e PC3 = 20,160%). In Table 2 are summarized the loadings values of all 40 characters for the first three principal components. Twenty nine characters are positively correlated with respective first principal component. Two total lengths and width characters (TLP, TWP), six carapace characters (LN5, LN6, WN5, WN6, LS5, LS4) and three plastron characters (LEP, LEN, LGU) are negatively correlated.

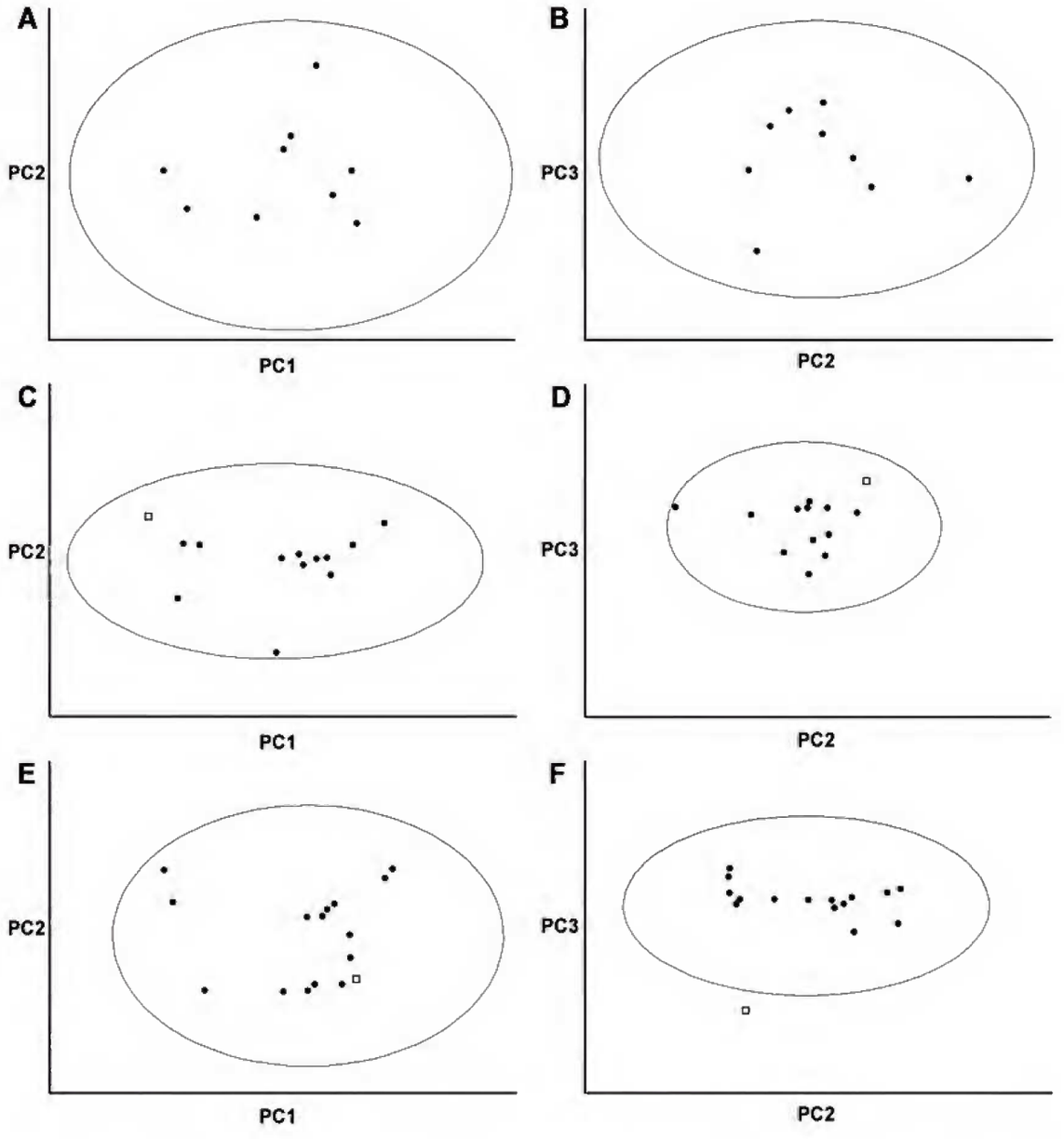

Fig.3- Bi-plot of Principal Components. (A) PC1 vs PC2 of total lengths and width measurements, (B) PC2 vs. PC3 of total lengths and width measurements (C) PC1 vs. PC2 of comprised measurements of the carapace, (D) PC2 vs. PC3 of comprised measurements of the carapace, (E) PC1 vs. PC2 of comprised measurements of the plastron, and (F) PC2 vs. PC3 of comprised measurements of the plastron. The circles indicate the 95% ellipse of normal distribution. Only the specimen MN 6782-V (white square) was out of this ellipse for PC2 vs. PC3 bi-plot of comprised measurements of the plastron.

Twenty four characters are positively correlated with respective second principal component. Nine carapace characters (LN1, LN2, WN, WN1, WN2, WN3, LS1, LS2, WS2) and seven plastron characters (LHY, LHP, LXI, WHH, WHX, LAB, LAN) are negatively correlated. Only 19 characters are positively correlated with respective third principal component. Despite that, all loadings values (positives and negatives) are relatively low.

DISCUSSION

The habitat of some extant Podocnemididae is similar to that inferred to "Tartaruguito" site based on geological studies and taphonomic data, which indicates a seazonal semi-arid climate to the region with waterlessness regions during dry station (Langer & Bertini, 1995; Henriques *et al.*, 2002, 2005). Based on this scenario, it is possible that the sample represents a single population of *Bauruemys elegans* which individuals agglomerated and died around a drying-up water body. Since a single population consists on a conjunct of semaforontes, the present morphometric study do not exclude the scenario proposed by Henriques (2006), on which at least ten distinct events of

TABLE 2. The first three Principal Components (PC) loadings of the three sorts of characters analyzed (total length and width, comprised measurements taken from the carapace, and comprised measurements taken from the plastron).

	Characters	Vector*	PC1	PC2	PC3
Total length and width	TLC	---	+ 0.6005	+ 0.2909	– 0.5014
	TWC	---	+ 0.5640	+ 0.4566	+ 0.2265
	TLP	---	– 0.5338	+ 0.5984	– 0.5496
	TWP	---	– 0.1909	+ 0.5906	+ 0.6287
Comprised measurements taken from the carapace	LN	1-2	+ 0.2869	+ 0.0105	+ 0.1791
	LN1	3-4	+ 0.2634	– 0.0519	– 0.0301
	LN2	5-6	+ 0.0847	– 0.0999	– 0.0311
	LN3	6-8	+ 0.0998	+ 0.0637	+ 0.0701
	LN4	8-10	+ 0.0596	+ 0.0748	+ 0.1698
	LN5	10-12	– 0.0091	+ 0.1715	– 0.0002
	LN6	12-14	– 0.0576	+ 0.2296	– 0.1786
	WN	2-2	+ 0.2846	– 0.0608	– 0.5441
	WN1	4-4	+ 0.1445	– 0.0083	+ 0.0922
	WN2	5-5	+ 0.0980	– 0.0158	+ 0.0624
	WN3	7-7	+ 0.1375	– 0.0166	+ 0.0388
	WN4	9-9	+ 0.0629	+ 0.0863	+ 0.1738
	WN5	11-11	– 0.0275	+ 0.2003	– 0.0455
	WN6	13-13	– 0.0511	+ 0.2098	– 0.1511
	LS1	15-16	+ 0.3187	– 0.0626	– 0.0479
	LS2	16-18	+ 0.2479	– 0.1272	+ 0.2101
	LS3	18-20	– 0.0400	+ 0.3741	– 0.0455
	LS4	20-22	– 0.0823	+ 0.3926	– 0.2741
	WS1	15-15	+ 0.5052	+ 0.2343	– 0.1103
	WS2	17-17	+ 0.4475	– 0.1143	– 0.0399
	WS3	19-19	+ 0.2434	+ 0.3420	+ 0.6279
	WS4	21-21	+ 0.0107	+ 0.5481	– 0.0595
Comprised measurements taken from the plastron	LEP	1-2	– 0.0120	+ 0.2498	+ 0.0091
	LEN	2-5	– 0.0028	+ 0.5564	+ 0.0351
	LHY	5-7	+ 0.5026	– 0.0028	– 0.4568
	LHP	7-9	+ 0.3343	– 0.0228	– 0.0727
	LXI	9-11	+ 0.2714	– 0.0495	+ 0.5388
	WEN	12-12	+ 0.0280	+ 0.5344	+ 0.0491
	WHH	7-13	+ 0.4267	– 0.0694	– 0.1460
	WHX	9-14	+ 0.2089	– 0.0353	+ 0.4131
	LGU	1-3	– 0.0272	+ 0.5367	+ 0.0192
	LHU	3-4	+ 0.0094	+ 0.0700	– 0.1106
	LPE	4-6	+ 0.2385	+ 0.1848	– 0.2274
	LAB	6-8	+ 0.3577	– 0.0099	– 0.1017
	LFE	8-10	+ 0.3625	+ 0.0735	+ 0.3726
	LAN	10-11	+ 0.1350	– 0.0301	+ 0.2939

(*) Landmarks used to trace linear measurements. See figure 1.

agglomeration of turtles might have occurred in this locality. The PCAs plotted a single specimen (MN 6782-V) out of 95% ellipse of normal distribution, that corresponds to PC2 and PC3 of comprised measurements of the plastron (see Fig2F). MN 6782-V is the biggest specimen analyzed, but it is represented only by the posterior portion of the carapace and medial portion of the plastron, and does not present any distinctive character in relation to *B. elegans*. Therefore, this out plot was interpreted as due to ontogeny.

Neural series is the most inter-specific variable element of the turtle shell (PRITCHARD, 1988). In the present sample, the measurements of neurals have shown little variation confirming the null hypothesis of having a single population of *Bauruemys elegans* in the sample. Interestingly, the length and width values of neural 5 and 6 showed negative loadings for PC1 and PC3. As pointed by PRITCHARD (1988), neurals might become fused in adults in several Testudines taxa, including extant Podocnemididae genus *Erymnochelys*. In *Podocnemis* and *Peltocephalus*, the number of neurals is usually seven. In *Erymnochelys*, the seven neurals are present in young specimens, but the last two neurals are liable to fuse in old animals (PRITCHARD, 1988). This trend might explain the negative loading values of neurals 5 and 6 as a tendency of reduction of size of those elements in the adult of *Bauruemys elegans*.

The observed morphometric difference among analyzed specimens supports the null hypothesis provided by taphonomic data, *i.e.*: that the sample represents a single population of *B. elegans*. Since no significant variation was observed, the explanation for this variation is assumed to be ontogenetic.

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